Zostera japonica: What is it and Where is it?

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Seagrasses are flowering plants from the monocot order Alismatales that returned to the marine environment between 17 and 75 million years ago (1). Seagrasses form an ecological group, not a taxonomic group (2), and as a result they encompass a variety of species characterized by adaptations to the marine environment (e.g. salt tolerance, underwater pollination, clonal growth, specialized leaves, etc.). Seagrass communities provide important ecosystem services (e.g. 3-dimensional habitat, primary production, nutrient removal, Ocean Acidification amelioration) which can contribute \$3500 to \$19000 ha^{-1} y^{-1} (3, 4). Seagrass populations worldwide are experiencing declines at a rate of about 110 km^2 y^{-1} and ~30% of seagrass areal extent has disappeared (3). The Pacific Northwest is one of a few places experiencing increased seagrass areal distribution and one of only two places known to have non-native seagrasses (5, 6).

Six seagrass species occur in Washington State (7). The dominant species based on areal extent are the native *Zostera marina* L. and non-native *Z. japonica* Aschers. & Graebn. Early descriptions of *Z. japonica* in North America were confounded by taxonomic uncertainty, morphological plasticity and contradictory descriptions of leaf-tip morphology, a key diagnostic feature. Early synonymous identifications have included *Z. nana*, *Z. noltii* and *Z. americana*. Researchers (2, 8) have concluded that the genus *Zostera* should be divided into subgenera and that *Z. japonica* be recognized under the subgenus *Zosterella*. Currently, *Z. japonica* is the recognized nomenclature, although recent genetic analyses indicate more work is needed (9).

Z. japonica is believed to have been introduced to North America with oysters during the early 20^{th} century. Harrison (10) cites personal communication with R. Scagel indicating that oysters may have been packed with eelgrass (species unknown), similar to the introduction of *Sargassum muticum*. The first large-scale introductions of Pacific oysters (*Crassostrea gigas*) from Miyagi Prefecture, Japan to Samish Bay in Puget Sound began in 1919 (11). In the early 1950's steps were taken to prevent accidental introduction of other organisms (12); consequently, it is likely that *Z. japonica* was introduced before the 1950's (13). The oyster- *Z. japonica* vector hypothesis is supported by genetic studies that indicate *Z. japonica* from British Columbia was strongly related to samples from Miyagi-Ishinomaki, Japan (14).

Within its native range, *Z. japonica* has an extremely broad latitudinal distribution, encompassing subtropical and temperate climates from southern Vietnam (~10º N latitude) to Kamchatka, Russia, (~50 º N latitude) (15, 16). Currently, *Z. japonica* has been reported from the Eel River, Humboldt County, California (40.6° N) at the southern end of its distribution almost to Campbell River, British Columbia (49.9° N; 17, 18) to the North. The earliest known collections of *Z. japonica* were from September 1957 at "south-east end of Long Island" in Pacific County, WA (19). Additional samples were collected from Padilla Bay, Boundary Bay

and Yaquina Bay during the 1970's (20, 21). In 2002, *Z. japonica* was reported from Indian Island in Humboldt Bay, CA (22). *Z. japonica* has been reported from most estuaries in Oregon and Washington (23, 24). Genetic analyses indicate that *Z. japonica* can be separated into populations with warm water and cold water affinities (14).

In its native range, *Z. japonica* has been reported to grow as deep as 3-7 m (datum not specified), although it typically grows at depths < 1 m (25, 26). Within colonized PNW estuaries, *Z. japonica* exhibits a distribution pattern that tends to minimize interactions with the native *Z. marina*. *Z. japonica* is found primarily in mid- to upper- intertidal zones, and has not been observed growing sub-tidally. In California, *Z. japonica* has been reported to occur between +0.9 and +1.2 m Mean Lower Low Water (MLLW) (22). In Oregon, *Z. japonica* typically occurs between +1 to +3 m MLLW (27). In Willapa Bay, Washington, *Z. japonica* was documented between +0.1 to +1.5 m MLLW, while *Z. marina* was only found < +0.6 m MLLW (28). In contrast, *Z. japonica* in Puget Sound has been found as deep as 0 m MLLW (29). Reports from British Columbia indicate it generally occurs between +1 to +3 m MLLW (30, 31).

In places where *Z. marina* and *Z. japonica* co-occur there are three distinct vertical zonation patterns (32). In the disjunct zonation, the *Z. japonica* bed is separated from the *Z. marina* bed by unvegetated sediments. These areas are characterized by a steep intertidal slope and a narrow fringing *Z. japonica* bed. The overlapping zonation pattern is characterized by mixed beds or discrete patches of both species at the same intertidal elevation. Overlapping zonation has been observed at sites with gently sloping topography. The mosaic zonation pattern is characterized by micro- topographic relief creating small pools with *Z. marina* interspersed with *Z. japonica* on well-drained hummocks. Mosaic sites, which often co-occur with the overlapping zonation pattern, are characterized by broad, expansive intertidal flats with very little slope (32, 33) and are generally localized in larger estuarine systems such as Boundary Bay, Padilla Bay, and Willapa Bay.

Physiological studies indicate *Z. japonica* is both euryhaline and eurythermal, with a lethal chronic temperature threshold between 32-35 ºC (34, 35). Assuming that transport vectors remain active, it is likely that, *Z. japonica* will continue to spread to the south until it reaches systems that regularly exceed its environmental tolerances (36, 37). Additionally, rising water temperatures expected to occur with global climate change may facilitate the northern expansion of *Z. japonica*. Consequently, it is likely that the distributional range of *Z. japonica* along the Pacific Coast of North America will continue to expand.

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